Attachment 2- Emission Reduction Calculations

<u>Ocean-Going Vessel Retrofit – ECA200 Upgrade (Page 1-9)</u>
<u>Ocean-Going Vessel with Fuel Cell Auxiliary Power (Page 10-14)</u>

<u>Ocean-Going Vessel Retrofit – ECA200 Upgrade</u>

The emission calculations for the proposed project were based on reports including <u>*EPA Methodologies for Estimating Port-Related and Goods Movement Mobil Source Emission Inventory*</u>, <u>*Port of Los Angeles Inventory of Air Emission CT 2013*</u> *and* <u>*San Pedro Bay Ports Emission Inventory Methodology Report*</u> and the data obtained from San Pedro Bay Ports.

Three typical sources that produce emissions from ships: propulsion engines, auxiliary engines, and boilers. Most of the ships utilized propulsion and auxiliary engines when they are approaching the port. The emissions were calculated separately for the main propulsion and auxiliary engines. The boilers' emission was not quantified in this proposal since it is not part of SCR retrofit, and the emissions will not change with the retrofit.

The emissions are estimated as a function of vessel power demand with energy expressed in kilowatt-hour (kW-hr) multiplied an emission factor and load adjustment factor, where the emission factor is expressed in terms of grams per kilowatt-hour (g/kW-hr). The load adjustment factor is also applied to the main engine. The load adjustment factor is also applied to the main engine. It was based on a slide valve test. The vessel that is newer than 2004 and equipped with MAN's 2-stroke engine has slide valves. The slide valve is designed to improve combustion properties by eliminating the fuel drips at the valve nozzles and improve the combustion process. Although more study on the slide valve at the below 25% engine load is needed. The load adjustment factors were applied to the main engine emission estimates for the proposed project since the emission reduction benefits associated with slide valves is currently being applied in both ports' emission inventories for all main engines. Low load adjustment factors also applied to the emission estimate for the propulsion engine when the engine is operating at less than 20% load since the emissions tend to increase as the engine load decrease.

Vessel movement activity is defined as the number of ship trips by trip type and segment. A trip type defines the ship's movement, and the segment defines the geographical area that the ship is operating within. Vessel trip includes arrivals, departures, and shifts. Trip segments are defined: between the at-sea portion and the precautionary zone (PZ) of the transit route of the ship trip, the segments within the PA, and the segments inside the breakwater. These trips are then processed to define time in mode and geographical segment. The purpose of this step is to estimate the engine power demand for that segment and multiple it by the amount of time spent in that particular mode, which estimates energy demand expressed as load times unit of time, e.g., kW-hr. To calculate the emission, the activity data, including vessel speed, engine data, main engine characteristics, fuel data, and vessel locations, were obtained from Port of Los Angeles. Port of Los Angeles has access to many data sources such as Marine Exchange of Southern California, Vessel Speed Reduction Program, HIS Markit, vessel boarding Program data, Automatic Identification System (AIS), and Environmental Ship Index Data.

This proposal is primarily focused on the NOx emissions and reductions using the SCRs, therefore, only NOx emissions are qualified here. The emission of the proposed project and emission reduction estimates are based on the information of the candidate vessel provided by the vessel operator and San Pedro Bay Ports. The ship characteristics for this project is listed in Table 2. The emission estimates (Table 3 and 4) are based on the vessel's power demand with energy expressed in kW-hr multiplied by, an emission factor, where the emission factor is expressed in terms of grams per kW-hr (Formula #1). The emission estimates are calculated separately for the main and auxiliary engines since they have different power ratings and emission factors. The emission estimates are based on the 200 nm, which is consistent with NECA. An IMO Tier III vessel would active the Tier III mode when it enters NECA of 200 nm from the coast of the United States. It is assumed that the vessel participates in the San Pedro Bay Ports, Santa Barbara, and Bay Area's Vessel Speed Reduction (VSR) program, and the vessel is operated at 12 knots or less within 40 nm from the coast. The emission estimate is likely to be higher if the vessel only participates in the San Pedro Bay Ports VSR due to a long distance that the vessel will operate at a higher engine load. The emission reduction expected after the retrofit is shown in Table 5. The annual emission and reductions are based on 8 port calls a year, which including arrival and departure. The number of calls for the estimate is based on the vessel operator's initial commitment during the discussion.

The diesel-cycle engines are not as efficient when operating at the less than 20% load. A EPA study (Analysis of Commercial Marine Vessels Emission and Fuel Consumption Data, February 2000) prepared by Energy and Environmental Analysis, Inc (EEAI) established a formula (Formula #2) for calculating emission factors under the low engine load conditions such as encountered during harbor maneuvering and when traveling slowly at sea (e.g., in the reduced speed zone.) Based on the study, the emission factors increase as the vessel speed and engine load decrease. Table 6 shows the vessel's operation profile used for the emission estimates in Table 2-5 and the emission factors at the lower than 20% load. More studies are needed to obtain the emission factors under the less than 20% load. Part of this proposed project includes the data collection under the low load engine condition and intention to address SCR efficiency at low engine load.

Vessel Characteristics

Main engine: 56,000kW	Auxiliary Engine: 4-Stroke, Medium Speed
IMO Tier II	Auxiliary at Berth: 980 kW
Maximum Vessel Speed:24 knots	Auxiliary Load Maneuvering: 2,666 kW
Container8000	Auxiliary Load At-Sea: 1,544 kw
Main and Auxiliary Engine Developed by MAN Energy Solutions	Using 0.1% Sulfur Fuel within 200nm
Tier II Emission Factor for NOx(g/kW-hr): 14.38 (main engine), 10.53 (auxiliary engine)	

Formula #1

Emission (ton) = (Propulsion Engine Power (kW) x Load Adjustment Factor x Activity (hr.) x Emission Factor x Low Load Adjustment Factor) ÷907,200

Vessel Operation Modes and Main Engine Low Load Emission Factors for NOx

Zone	Distance (nm)	Main Engine Load Factor	Speed (knots)	Low load Emissions Factor, (below 20% load)	Zone Time (hours)	Load Adjustment Factor
In-bound NECA	160	47%	19		8.42	1
VSR-SPBP	40	12%	12	1.14	3.33	1.5
In-bound Maneuvering	12	7%	10	1.45	1.2	1.67
At-berth-SPBP	0	0%	0		3	
Out-bound Maneuvering	12	7%	10	1.45	1.2	1.67
VSR- out-bound SPBP	40	12%	12	1.14	3.33	1.5
VSR-SB	95	7%	10	1.45	9.5	1.67
Open Water	195	47%	19		10.26	1
VSR-Bay Area to Maneuvering	30	7%	10	1.45	3	1.67
In-bound Oakland Maneuvering	10	7%	10	1.45	1	1.67
At-Berth Oakland	0	0%	0		3	
Out-bound Oakland Maneuvering	10	7%	10	1.45	1	1.67
VSR-Bay Area	30	7%	10	1.45	3	1.67
Out Bound NECA	170	47%	19		8.951	

Table 2.9: Pollutant Emission Factors for Auxiliary Engines, g/kW-hr

Engine Category	IMO Tier	Model Year Range	PM_{10}	$PM_{2.5}$	DPM	NOx	SOx	CO	HC
Using 2.7% Sulfur HFO Fuel									
Medium speed auxiliary	Tier 0	1999 and older	1.50	1.20	1.50	14.70	12.3	1.1	0.4
Medium speed auxiliary	Tier I	2000 to 2011	1.50	1.20	1.50	13.00	12.3	1.1	0.4
Medium speed auxiliary	Tier II	2011 to 2016	1.50	1.20	1.50	11.20	12.3	1.1	0.4
Medium speed auxiliary	Tier III	2016 and newer	1.50	1.20	1.50	2.80	12.3	1.1	0.4
High speed auxiliary	Tier 0	1999 and older	1.50	1.20	1.50	11.60	12.3	0.9	0.4
High speed auxiliary	Tier I	2000 to 2011	1.50	1.20	1.50	10.40	12.3	0.9	0.4
High speed auxiliary	Tier II	2011 to 2016	1.50	1.20	1.50	8.20	12.3	0.9	0.4
High speed auxiliary	Tier III	2016 and newer	1.50	1.20	1.50	2.10	12.3	0.9	0.4
Using 0.1% S MGO Fuel									
Medium speed auxiliary	Tier 0	1999 and older	0.255	0.240	0.255	13.82	0.455	1.4	0.6
Medium speed auxiliary	Tier I	2000 to 2011	0.255	0.240	0.255	12.22	0.455	1.4	0.6
Medium speed auxiliary	Tier II	2011 to 2016	0.255	0.240	0.255	10.53	0.455	1.4	0.6
Medium speed auxiliary	Tier III		0.255	0.240	0.255	2.63	0.455	1.4	0.6
High speed auxiliary	Tier 0	1999 and older	0.255	0.240	0.255	10.90	0.455	1.1	0.5
High speed auxiliary	Tier I	2000 to 2011	0.255	0.240	0.255	9.78	0.455	1.1	0.5
High speed auxiliary	Tier II	2011 to 2016	0.255	0.240	0.255	7.71	0.455	1.1	0.5
High speed auxiliary	Tier III	2016 and newer	0.255	0.240	0.255	1.97	0.455	1.1	0.5

Table 2.7: Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Slide Valves

Load	PM	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
1%	0.36	0.36	0.36	1.90	1.10	0.12	1.36	1.10	1.90	1.36
2%	0.37	0.37	0.37	1.86	1.10	0.12	1.32	1.10	1.86	1.32
3%	0.38	0.38	0.38	1.82	1.09	0.12	1.28	1.09	1.82	1.28
4%	0.38	0.38	0.38	1.78	1.09	0.12	1.24	1.09	1.78	1.24
5%	0.39	0.39	0.39	1.74	1.09	0.12	1.20	1.09	1.74	1.20
6%	0.40	0.40	0.40	1.70	1.08	0.12	1.17	1.08	1.70	1.17
7%	0.41	0.41	0.41	1.67	1.08	0.12	1.14	1.08	1.67	1.14
8%	0.41	0.41	0.41	1.63	1.08	0.12	1.11	1.08	1.63	1.11
9%	0.42	0.42	0.42	1.60	1.07	0.12	1.08	1.07	1.60	1.08
10%	0.43	0.43	0.43	1.57	1.07	0.12	1.05	1.07	1.57	1.05
11%	0.44	0.44	0.44	1.53	1.07	0.26	1.02	1.07	1.53	1.02
12%	0.45	0.45	0.45	1.50	1.07	0.39	0.99	1.07	1.50	0.99
13%	0.45	0.45	0.45	1.47	1.06	0.52	0.97	1.06	1.47	0.97
14%	0.46	0.46	0.46	1.45	1.06	0.64	0.94	1.06	1.45	0.94
15%	0.47	0.47	0.47	1.42	1.06	0.75	0.92	1.06	1.42	0.92
16%	0.48	0.48	0.48	1.39	1.06	0.85	0.90	1.06	1.39	0.90
17%	0.49	0.49	0.49	1.37	1.05	0.95	0.88	1.05	1.37	0.88
18%	0.49	0.49	0.49	1.34	1.05	1.04	0.86	1.05	1.34	0.86
19%	0.50	0.50	0.50	1.32	1.05	1.12	0.84	1.05	1.32	0.84
20%	0.51	0.51	0.51	1.30	1.05	1.20	0.82	1.05	1.30	0.82
21%	0.52	0.52	0.52	1.28	1.04	1.27	0.81	1.04	1.28	0.81
22%	0.53	0.53	0.53	1.26	1.04	1.34	0.79	1.04	1.26	0.79
23%	0.54	0.54	0.54	1.24	1.04	1.40	0.78	1.04	1.24	0.78
24%	0.54	0.54	0.54	1.22	1.04	1.46	0.76	1.04	1.22	0.76
25%	0.55	0.55	0.55	1.20	1.03	1.51	0.75	1.03	1.20	0.75

Table 2.7 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Slide Valves

Load	PM	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
26%	0.56	0.56	0.56	1.19	1.03	1.55	0.74	1.03	1.19	0.74
27%	0.57	0.57	0.57	1.17	1.03	1.59	0.73	1.03	1.17	0.73
28%	0.58	0.58	0.58	1.16	1.03	1.63	0.72	1.03	1.16	0.72
29%	0.59	0.59	0.59	1.14	1.03	1.66	0.71	1.03	1.14	0.71
30%	0.60	0.60	0.60	1.13	1.02	1.68	0.70	1.02	1.13	0.70
31%	0.60	0.60	0.60	1.12	1.02	1.70	0.70	1.02	1.12	0.70
32%	0.61	0.61	0.61	1.10	1.02	1.72	0.69	1.02	1.10	0.69
33%	0.62	0.62	0.62	1.09	1.02	1.74	0.69	1.02	1.09	0.69
34%	0.63	0.63	0.63	1.08	1.02	1.75	0.68	1.02	1.08	0.68
35%	0.64	0.64	0.64	1.07	1.02	1.75	0.68	1.02	1.07	0.68
36%	0.65	0.65	0.65	1.06	1.01	1.75	0.68	1.01	1.06	0.68
37%	0.66	0.66	0.66	1.05	1.01	1.75	0.67	1.01	1.05	0.67
38%	0.67	0.67	0.67	1.05	1.01	1.75	0.67	1.01	1.05	0.67
39%	0.68	0.68	0.68	1.04	1.01	1.74	0.67	1.01	1.04	0.67
40%	0.69	0.69	0.69	1.03	1.01	1.73	0.67	1.01	1.03	0.67
41%	0.70	0.70	0.70	1.03	1.01	1.72	0.67	1.01	1.03	0.67
42%	0.70	0.70	0.70	1.02	1.01	1.71	0.68	1.01	1.02	0.68
43%	0.71	0.71	0.71	1.02	1.01	1.69	0.68	1.01	1.02	0.68
44%	0.72	0.72	0.72	1.01	1.00	1.67	0.68	1.00	1.01	0.68
45%	0.73	0.73	0.73	1.01	1.00	1.65	0.69	1.00	1.01	0.69
46%	0.74	0.74	0.74	1.00	1.00	1.62	0.69	1.00	1.00	0.69
47%	0.75	0.75	0.75	1.00	1.00	1.60	0.70	1.00	1.00	0.70
48%	0.76	0.76	0.76	1.00	1.00	1.57	0.70	1.00	1.00	0.70
49%	0.77	0.77	0.77	0.99	1.00	1.54	0.71	1.00	0.99	0.71
50%	0.78	0.78	0.78	0.99	1.00	1.51	0.71	1.00	0.99	0.71

Table 3.2: Average Auxiliary Engine Load Defaults, kW

Vessel Type	Transit	Maneuvering	Berth Hotelling	Anchorage Hotelling
Auto Carrier	520	1,238	859	622
Bulk	255	675	150	253
Bulk - Heavy Load	255	675	150	253
Container - 2000	968	2,099	966	942
Container - 4000	1,454	2,314	1,148	1,124
Container - 5000	1,811	3,293	945	967
Container - 6000	1,509	2,237	1,039	1,464
Container - 7000	1,498	2,445	1,225	884
Container - 8000	1,544	2,666	980	1,055
Container - 9000	1,514	2,864	1,061	996
Container - 10000	1,757	2,210	1,163	1,051
Container - 11000	2,213	2,944	1,341	1,684
Container - 13000	1,678	2,418	1,234	1,220
Container - 14000	1,475	2,105	1,118	1,114
Container - 17000	1,483	1,994	1,000	1,000
Cruise	na	na	na	na
General Cargo	516	1,439	722	180
Ocean Tug (ATB/ITB)	79	208	102	79
Miscellaneous	643	597	228	200
Reefer	513	1,540	890	513
RoRo	434	1,301	751	434
Tanker - Chemical	658	890	816	402
Tanker - Handysize	537	601	820	560
Tanker - Panamax	561	763	623	379
Tanker - Aframax	576	719	724	474

Table 2.3: Pollutant Emission Factors for Diesel Propulsion and Steam (Boiler) Propulsion and Gas Turbine Engines, g/kWh

Engine Category	IMO Tier	Model Year Range	PM_{10}	$PM_{2.5}$	DPM	NO_x	SOx	CO	HC
Using 2.7% Sulfur HFO Fuel									
Slow speed propulsion	Tier 0	1999 and olde	1.50	1.20	1.50	18.1	10.5	1.4	0.6
Slow speed propulsion	Tier I	2000 to 2011	1.50	1.20	1.50	17.0	10.5	1.4	0.6
Slow speed propulsion	Tier II	2011 to 2016	1.50	1.20	1.50	15.3	10.5	1.4	0.6
Slow speed propulsion	Tier III		1.50	1.20	1.50	3.6	10.5	1.4	0.6
Medium speed propulsion	Tier 0	1999 and olde	1.50	1.20	1.50	14.0	11.5	1.1	0.5
Medium speed propulsion	Tier I	2000 to 2011	1.50	1.20	1.50	13.0	11.5	1.1	0.5
Medium speed propulsion	Tier II	2011 to 2016	1.50	1.20	1.50	11.2	11.5	1.1	0.5
Medium speed propulsion	Tier III	2016 and new	1.50	1.20	1.50	2.8	11.5	1.1	0.5
Gas turbine	na	All	0.05	0.04	0.00	6.1	16.5	0.2	0.1
Steam propulsion engine and boiler	na	All	0.80	0.64	0.00	2.1	16.5	0.2	0.1
Using 0.1% S MGO Fuel									
Slow speed propulsion	Tier 0	1999 and olde	0.255	0.240	0.255	17.01	0.389	1.4	0.6
Slow speed propulsion	Tier I	2000 to 2011	0.255	0.240	0.255	15.98	0.389	1.4	0.6
Slow speed propulsion	Tier II	2011 to 2016	0.255	0.240	0.255	14.38	0.389	1.4	0.6
Slow speed propulsion	Tier III		0.255	0.240	0.255	3.38	0.389	1.4	0.6
Medium speed propulsion	Tier 0	1999 and olde	0.255	0.240	0.255	13.16	0.426	1.1	0.5
Medium speed propulsion	Tier I	2000 to 2011	0.255	0.240	0.255	12.22	0.426	1.1	0.5
Medium speed propulsion	Tier II	2011 to 2016	0.255	0.240	0.255	10.53	0.426	1.1	0.5
Medium speed propulsion	Tier III	2016 and new	0.255	0.240	0.255	2.63	0.426	1.1	0.5
Gas turbine	na	All	0.050	0.040	0.000	5.73	0.611	0.2	0.1
Steam propulsion engine and boiler	na	All	0.136	0.128	0.000	1.97	0.611	0.2	0.1

Emission Results

Baseline Emissions from Main and Auxiliary Engines
(Tier II Emission Level)

	NOx Main Engine (tons)	NOx Auxiliary Engine (tons)	Total Emission (tons)
Per Port Call	15.73	1.07	**16.80**
Annual*	125.88	8.55	**134.43**

*Annual emission is based on 8 port calls a year

Emissions from Main and Auxiliary Engines after the SCR Installation (ECA200)

	NOx Main Engine (tons)	NOx Auxiliary Engine (tons)	Total Emission (tons)
Per Port Call	3.72	0.27	**3.99**
Annual*	29.76	2.14	**31.90**

*Annual emission is based on 8 port calls a year

Emission Reductions from Main and Auxiliary Engines after ECA 200 Upgrade

	NOx Main Engine (tons)	NOx Auxiliary Engine (tons)	Total Emission Reduction (tons)
Per Port Call	12.01	0.80	**12.81**
Annual*	96.08	6.40	**102.48**

*Annual reduction is based on 8 port calls a year

Progress toward meeting NAAQS attainment at the designated area:

The South Coast Air Basin was identified by EPA as nonattainment areas and ranked as one of the top five most polluted areas for the 8-hour ozone and $PM_{2.5}$. Based on the South Coast AQMD's 2016 Air Quality Management Plan (AQMP), the most significant air quality challenge in the Basin is to reduce NOx emission sufficiently to meet the upcoming ozone standard deadlines. Based on the inventory and modeling results, 522 tons per day (tpd) of total Basin NOx 2012 emissions are projected to drop to 255 tpd and 214 tpd in the 8-hour ozone attainment years of 2023 and 2031 respectively, due to the continued implementation of already adopted regulatory actions. The analysis suggests that total Basin emissions of NOx must be reduced to approximately 141 tpd in 2023 and 96 tpd in 2031 to attain the 8-hour ozone standard. This represents an additional 45% reduction in NOx in 2023, and an additional 55% NOx reduction beyond 2031 levels.

The estimated NOx reductions for the proposed project is 12.81 tons per port call and 102.48 tons annually with the cost-effectiveness of $59,108 per ton of NOx reductions if the vessel operates for 2 years after the upgrade. It is expected that the vessel will remain in service for at least 10 years. The South Coast AQMD is expecting a 30 tpd of reduction from the OGVs by 2023. The proposed project is expected to achieve 12.81/call which is more than 30% of daily reductions we are expecting.

Cost-Effectiveness of ECA200

	Effective Nautical Mile (NM)	Emission Reductions	Annual Emission Reduction - 8 Port Calls (ton)	2- Year Emission Reduction - 16 Port Calls (ton)	Project Cost	Cost Effectiveness (8 calls/year for 2 year) $/ton
Proposed Project	200	12.81 tons/call	102.48	204.96 tons	$12,114,700	$59,108

Ocean-Going Vessel with Fuel Cell Auxiliary Power

Emission Calculation and Reduction Results:

Annual Emissions reduction at Port of Los Angeles to 200 nautical miles distance

	Existing Arrangement (Diesel Auxiliary Engines) (Tons)	**Proposed Arrangement (Fuel Cell Auxiliary Power) (Tons)**	**Emission Reductions**	**Reduction in %**
NOx	2.45	0.54	1.91	78%
CO	0.61	0.15	0.46	76%
Hydrocarbons	0.81	0.18	0.63	77%
PM (Soot+fuel ash + lube ash)	0.36	0.08	0.28	78%
CO_2	696.84	283.54	413.30	59%

Annual Emissions Reduction for the Complete Vessel Itinerary

	Existing Arrangement (Diesel Auxiliary Engines) (Tons)	**Proposed Arrangement (Fuel Cell Auxiliary Power) (Tons)**	**Emission Reductions**	**Reduction in %**
NOx	24.07	5.15	18.92	**79%**
CO	5.98	1.45	4.54	**76%**
Hydrocarbons	7.98	1.78	6.19	**78%**
PM (Soot+fuel ash + lube ash)	3.49	0.75	2.74	**79%**
CO2	6847.98	3865.84	2982.14	**44%**

Emission Calculation Methodology:

1. Containership duration and energy consumption estimation:
    i. Based on the itinerary of the containership, speed in different modes, the duration per trip is estimated.
    ii. Based on the total duration of each trip, total number of trips are estimated

iii. Multiplying the number of trips and duration in each trip, annual number of hours spent in different modes and different legs of itinerary are estimated
iv. Average load in different modes is estimated in the "Air Emissions Inventory CY 2018, Port of Los Angeles" or Containership-4000 is considered
v. Multiplying the duration in each mode with the average load in each mode, annual energy (kWh) consumed in each leg of the itinerary and total itinerary is estimated

2. Existing arrangement fuel consumption and emissions calculation:
   i. Specific fuel oil consumption of the engines is obtained from the engine manufacturers documents in grams of fuel per kWh (g/kWh)
   ii. Similarly, emission factor for different pollutants is obtained from engine manufacturers documents in grams of emission per gram of fuel
   iii. Tier III compliant engines, NOx emissions are estimated to be in compliant with IMO limits
   iv. The annual energy estimated in step 1.v is multiplied with specific fuel oil consumption to obtain fuel consumed and with emission factor to estimate the pollutant emissions in each leg of the itinerary and total emissions of the containership
   v. Emissions pertaining to energy consumed while at berth from Shore Power is calculated by multiplying the emission factors of LADWP's non-baseload output emission rate (emission per kWh) as per "Emissions & Generation Resource Integrated Database (eGRID), 2018".
3. Proposed arrangement fuel consumption and emissions calculation:
   i. Fuel Cell is sized to meet all the energy (kWh) requirements at berth and engines are not in running mode while at berth.
   ii. The specific fuel oil consumption of fuel cell is obtained considering the estimated calorific value of LNG and efficiency of Fuel Cell as provided by Bloom Energy
   iii. During other modes, Fuel Cell will operate in parallel with engines. While fuel cells will operate at full capacity, engines will provide the rest of the energy requirements
   iv. Considering the arrangement in 3.i and 3.ii, annual energy (kWh) supplied and fuel consumed by Fuel Cells and Engines in different modes and different legs of the itinerary is estimated
   v. Emission factor in grams of pollutant per kWh for different pollutants from Fuel Cell are obtained from Bloom Emission test results. Annual emissions in each mode and each leg of the itinerary from Fuel Cell is obtained by multiplying the emission factor and energy (kWh) supplied by Fuel Cells
   vi. Similar to step 2.iv, fuel consumed and emissions from engines is obtained by multiplying Engine emission factors and the energy (kWh) supplied by the engines while running in parallel with Fuel Cell
   vii. Adding the emissions from fuel cell estimated in step 3.iv and 3.v will provide annual emissions in each leg and total itinerary from proposed arrangement
4. Annual emissions reduction:
   i. By subtracting the emissions from proposed arrangement estimated in step 3.vi from emissions from existing arrangement estimated in step 2.iv and 2.v, the annual reduction of emissions in each leg of itinerary and total annual emissions of the containership is obtained
   ii. The emissions reduction achieved for the portions where the containership is operating within 200 nautical miles from Port of Los Angeles is calculated separately in a similar manner
5. Savings Estimation:
   i. Annual fuel consumption by engines along with Lube Oil (major consumable) is estimated as per step 2.iv and multiplied with average price of the fuel and lube oil respectively.

ii. Annual cost of Shore Power is estimated based on energy consumer by containership while at Berth and the LADWP's tariff applicable for "Port of Los Angeles Alternative Maritime Power"

iii. Adding 5.i and 5.ii will provide the cost of energy under existing arrangement

iv. Annul fuel consumption by Fuel Cell and Engines along with Lube Oil for engines is estimated as per steps 3.iv and 3.vi and multiplied by the price of respective fuel to obtain total cost of energy for proposed arrangement

v. By subtracting total cost of energy for proposed arrangement from total cost of energy under existing arrangement will provide the estimated savings from the project

Vessel Operating Profile	Port A			200 nautical miles from Port of LA			Port of LA	200 nautical miles from Port of LA			Port B			Port A		
Itinerary Stage	0	1a	1b	1c	1d	1e	2	3a	3b	3c	3d	3e	4	5a	5b	5c
Mode of Operation	At Berth	Maneuvering	Transit	Transit	Transit	Maneuvering	At Berth	Maneuvering	Transit	Transit	Transit	Maneuvering	At Berth	Maneuverin	Transit	Maneuvering
Average Load kW	1148	2314	1454	1454	1454	2314	1148	2314	1454	1454	1454	2314	1148	2314	1454	2314
Duration during a round trip	24	0.3	18.6	10.0	3.2	0.3	24.0	0.3	3.2	7.3	93.1	0.3	42.0	0.3	102.1	0.3
No of trips annually	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26
Annual Hours	624.0	6.5	484.3	260.0	82.3	6.5	624.0	6.5	82.3	189.1	2420.4	6.5	1092.0	6.5	2654.4	6.5
Annual kWh	716040	15041	704099.5	378040	119712.67	15041	716040	15041	119712.7	274938.1818	3519208.727	15041	1253070	15041	3859444.7	15041

Emission Factors - g/kWh	Engine Emissions[2]		Shore Power Emissions[3]	
NOx#	2.41	g/kWh	0.31	g/kWh
CO	0.6	g/kWh	0	g/kWh
Hydrocarbons	0.8	g/kWh	0.035	g/kWh
PM (Soot+fuel ash + lube ash)	0.35	g/kWh	0	g/kWh
CO2 Emission factor (IMO)	3.206	g/g of fuel	534	g/kWh

Fuel Cell Emissions - g/kWh[4]	Source:Bloom Fuel Cell Emission Test Results			
NOx	0.00077	g/kWh		
CO	0.01542	g/kWh		
Hydrocarbons	0.00721	g/kWh		
PM (Soot+fuel ash + lube ash)	0	g/kWh		
LNG CO2 Emission factor	2.75	g/g of fuel		

Tier 3:

Annual Emissions reduction at Port of Los Angeles to 200 nautical miles distance

	Existing Arrangement (Diesel Auxiliary Engines) (Tons)	**Proposed Arrangement (Fuel Cell Auxiliary Power) (Tons)**	**Emission Reductions**	**Reduction in %**
NOx	2.45	0.54	1.91	78%
CO	0.61	0.15	0.46	76%
Hydrocarbons	0.81	0.18	0.63	77%
PM (Soot+fuel ash + lube ash)	0.36	0.08	0.28	78%
CO2	696.84	283.54	413.30	59%

Annual emission is based on 26 port calls a year and at berth reduction is not included

Annual Emissions reduction for the complete Vessel Itinerary (Entire Voyage)

	Existing Arrangement (Diesel Auxiliary Engines) (Tons)	**Proposed Arrangement (Fuel Cell Auxiliary Power) (Tons)**	**Emission Reductions**	**Reduction in %**
NOx	24.07	5.15	18.92	**79%**
CO	5.98	1.45	4.54	**76%**
Hydrocarbons	7.98	1.78	6.19	**78%**
PM (Soot+fuel ash + lube ash)	3.49	0.75	2.74	**79%**
CO2	6847.98	3865.84	2982.14	**44%**